

Toward a Non-Reductionist Perspective of Thinking in Science

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1. Knowing versus Doing

Sasha: This manuscript is quite timely given the current interest in having students “do science,” as opposed to simply being told about it. Couple this with the obsession for having children score highly on standardized tests, an outcome that many believe is best solved through direct instruction. Many of us react to the idea that learning (or knowing) is a process of acquiring information, instead treating it as a participatory act involving rich relations among the formal content, rich contexts, and engaging tasks (Sfard, 1998). I certainly subscribe theoretically to the situativity view and the conviction that context matters, as well as the pedagogical conviction that students should learn science by addressing meaningful problems in rich contexts. However, a core question that emerges is how do we engage students in rich contexts that situate the context while still supporting them in interacting with the more formal underlying concepts and theories?

SungWon: The interesting point I find here is that the context becomes really rich insofar as the formal concepts and theories emerge to the students as resources for realizing their motive. I am reminded that the artifact designing activity introduced in this study is part of a project (Simple Machines Curriculum) that took a “design experiment” approach. The research team participated in designing curricular activities and improving schooling through the integration with the research practice. In this research practice, students together with researchers and school teachers constitute the collective subject who develops school practice in collaboration. Researchers and school teachers are already there, as resources that provide students with cultural possibilities. The issue then becomes the mechanism, how students come to recognize the resources as resources and enact them. An important aspect that needs more attention is the role of the sense of collectivity (solidarity) that developed between students, teachers, and researchers has in this process.

Steve: While recognizing available resources as resources for the collective this response does not deal specifically with learning science concepts. I am left to ponder a familiar question: “Where is the science?” I am reminded here of the *A Private Universe* program where the notion that hands-on activities leads to science learning was challenged. This paper takes us back to this issue by reminding us that any-old-activity does not lead to learning concepts that are consistent with current scientific communities. I think this paper gives us the opportunity to get re-acquainted with the metaphor hands-on minds-on, but in a very different way. It effectively unpacks what might be involved in learning through students’ participation of designing activities, specifically, or laboratory activities, more generally. I accept that resistance|contradiction might lead to learning new practices such as using a saw, but we don’t see any evidence in this paper of how this applies to conceptual learning in science (e.g. force, energy). So, where is the science learning?

Michael: In part, the conceptual aspects have not been addressed in this paper, it almost exclusively is concerned with processes. I can assure you that there were opportunities in the curriculum for students to be confronted with concepts and

theories in situations where these were applicable. Thus, as the teacher, I brought pulleys to the classroom and set up various problems in whole-class situations, which then were taken as topics for prediction, observation, and discussion. The students thereby were confronted with different pulley configurations and forces, the magnitudes of which differed across the system. Similarly, I brought first-, second-, and third-class levers, inclined planes, springs and elastics, and wedges, each of which became a topic of talk and an occasion for introducing relevant concepts. Whether students found these concepts useful and under which conditions was itself an important outcome of our project (e.g., Roth, McGinn, Woszczyzna, & Boutonné, 1999).

Sasha: Similarly, I further found myself interested in both how non-material concepts can be learned from laboratory performances as well as how we can establish tasks such that students need to enlist these concepts to inform their actions. The former question deals with the idea of engaging learners in tasks through which these non-material concepts are embodied (i.e., designing a building that draws on notions of ‘triangulation’), whereas the latter question around embedding non-material concepts deals with how learning tasks can be established so that non-material concepts are opportunistically enlisted (whether by the learner or more-informed other) into the learning experience. I found myself wondering if *embodied* is more instructionally useful than *embedded* or whether the distinction is even meaningful in practice.

Michael: In the way you articulate these issues, I seem to detect an intention to separate out the material and non-material, ideal aspects of practical activity. Personally I do not think that this is possible. As cultural-historical activity theorists have emphasized since Marx, *thinking* is the dialectical complement of *material activity* (e.g., Vygotsky, 1986). This means that we cannot theorize each independently of the other, because they are *interdependent*. In fact, they are one-sided expressions of (inherently concrete) *praxis*. Praxis is the (theoretical, real) unit that “sublates” the contradiction between thinking and doing. Because they are dialectically related, there is therefore no longer a problem of how thinking relates to the world (the “grounding problem” of artificial intelligence and cognitive science) but it always relates to the material world where it can therefore effect change. The one difference between an activity theorist’s use and a traditional approach is that (a) *thinking* tremendously exceeds cogitation and (b) *thinking* also includes non-thematizing aspects of the process.

SungWon: In the example of the three girls’ sawing, the actions could not be understood without considering their orientation toward designing machines that transform potential energy into kinetic energy. That is, the concept of “energy transformation” is always an aspect of human material practice. Every action involves the semiotic (communicative, intentional) aspect toward a collective motive on the one hand and the material aspect on the other.

Michael: And adopting the motive, the subject of activity also adopts emotional, ethico-moral, and motivational aspects that may not be explicit at all. Again, the description of practical *thinking* may require us to use the concepts of energy transformation and others, even though the children may not have used the words.

Steve: I accept that student designers might demonstrate their practical thinking in the making of an artifact, but teachers will usually expect such thinking to be transformed into written and/or spoken forms of communication before they accept that they have understood the related concepts; that is, to write and speak as legitimate members of the designing community or classroom.

SungWon: In this dialectic framework, knowing a non-material concept is an aspect of practical activity. In terms of “embodied” I attend to all kinds of human material practice, not only manipulating materials but also making utterances—the human body produces utterances with different intensities and pitches (prosody). Learning scientific concepts changes the way students relate to the world not only verbally but also non-verbally. Talking about phenomena in scientific terms constitutes an important but one aspect of communicative act, relating to the world, which is deeply embedded in concrete experience of material practices. In fact, people communicate not through words but through all kinds of resources that the bodies produce in concrete situations.

Sasha: Theoretically, I am struck with whether the authors find the metaphors of acquisition versus participation relevant. Are the authors simply enlisting the latter in all cases described, and their notion of epistemic distancing and third person reflection is simply another form of participation. While I might predict the author’s response, I wonder if they think that one involves more cognition and symbolic manipulation, while the other involves more hands-on participation with less formal cognition. When does one start “knowing” and when are they “doing?” How does this relate to mind-body dualism? Does calling it dialectic sidestep the problem or solve it? It seems to me that positioning both in the relations is one potential response, but I am left wondering if the authors feel that knowing and doing are qualitatively different things? Also, in any one activity where does one start and the other stop. On a related note, when does a situated performance become a non-material concept? Theoretically, what is the process, and what is the underlying ontological distinction between using a concept as a resource or tool for a situation and abstracting it out such that it has other-context potential?

Steve: I agree. Sasha’s interesting questions can be side stepped when applying dialectic logic. It short-circuits many either-or debates that have been mostly unproductive. I am reminded here of Willison and Taylor’s (2006) position with respect to the apparent opposition of constructivism and objectivism. They argued that when viewed metaphorically rather than theoretically, constructivism and objectivism “can provide different viable and valuable understandings about science teaching and learning (and the nature of science)” (p. 34). It might be more fruitful then to continue to think of mind and body, for example, as complementary perspectives that help us understand more deeply how we come to know.

Michael: Within a dialectical framework, the “complementary perspectives” are one-sided expressions of some whole unit. Analysis cannot proceed by adding together or juxtaposing these complementary perspectives. To understand the relation between these perspectives, we need to begin with the unit, which here is the concrete praxis that realizes a societal activity. In concrete praxis, there is no distinction between *thinking* and (material) *doing*; and communicating, for example, is subordinate to activity as a whole but different from *thinking* (A. A. Leont’ev, 1971). And this

praxis, at each moment, is the irreducible unit of object/motives and goals (“ideal,” plans, *thinking*) and concrete operations that realize them (A. A. Leont’ev, 1971).

SungWon: Theories of situated learning attend to sociocultural aspects of human practice, conceptualizing them in terms of context, community, symbols, and so on. Yet, I find that they have been silent about the materiality of practice that enables the very situativity.

Michael: I believe this silence has its source in the way Engeström’s (1987) triangle makes salient the structural aspects of an activity (system), and simultaneously pushes agentive (*thinking*) into the background. Simultaneously, those interested in cognition reduce activity to rational cogitation and neglect to co-thematize the material and non-conscious aspects of activity.

SungWon: Cases presented in the article show that engagement in an activity is an embodied practice and as well is epistemic distancing. Changing participation involves not only changes of *social* relations but also those of *material* practice. I find possibilities of this dialectic understanding in the framework of cultural historical activity theory—the concept of object, for example. The embodied frameworks articulated in this paper leads us to understand that using cultural resources in another context different than before is a matter of making variations, in which cultural possibilities emerge saliently to actors, rather than seeing it as a mysterious process of abstraction and application of something.

2. Facilitating Learning

Sasha: On a related note, this manuscript deals with an incredibly important tension that has received sparse attention by situativity theorists given its relevance to the theory having practical impact. In particular, it grapples with the tension of how “material laboratory activities allow students to learn about material phenomena in terms of non-material concepts and theories.” Whereas situativity theorists have helped us appreciate the interrelations of content and context, a fundamental concern of many critics is that they have left underconceptualized the role of more generalizable theories (Shavelson, Towne, & Fuere, 2004). Clearly, when learning a discipline in the context of formal learning contexts such as schools, presenting abstract concepts runs the risk of them simply becoming inert facts to be memorized (Whitehead, 1929). On the flip side, does grounding without some level of epistemic distance lead to rich appreciation of one set of particular dynamics without an appreciation for how these relate to other contexts? That is, do understandings become too situated? If one agrees that transfer conceptualized in some way is important, then at some point the learner needs to appreciate that which is specific to the situation (“variant,” to use an ecological term) and that which has cross-contextual application (“invariant”). Without such an appreciation the content has gained grounding at the expense of useful knowledge. Ironically, this is why situativity theorists have argued for learning through rich situational contexts.

Michael: Again, you raise a host of interesting issues. On the one hand, content and context are but two one-sided expressions of the unit as a whole from a dialectical perspective. Any activity is defined by the societal motive, its object (content); the

activity realizes the motive, itself mediated by the tools, division of labor, rules, community, and so on. But these are the structural aspects of the context. Empirical support comes from a series of studies we have conducted, which on the one hand involved expert/expert studies using think aloud protocols and in-depth ethnographies involving some of these same participants (most hold PhD degrees). These studies show that on the one hand, the experts tremendously struggle doing some elementary, first-year university interpretation tasks of graphs and associated concepts in their own field, let alone in different fields (Roth, 2003). At the same time, my ethnographic work shows that these same scientists who struggled in one setting used much more complex graphs and associated concepts in their own work. Most interestingly, in the few cases where there existed structural similarities between the graphs in the think aloud sessions and graphs from their own work, I could not observe an instance of transfer.

Steve: We rarely “see” evidence of “transfer” within classroom studies because we are still focusing on the actions of participants within this particular activity system. If we could track students’ activities to out-of-school activity systems where the cultural resources produced within the classroom context had some perceived value or relevance for these students in these different situations, we would have compelling evidence for transfer.

Michael: When we think of “transfer,” we need to be cautious and define what we mean by the term, and what if anything transfers between two different activity systems. Because when activity systems are the unit of analysis, then the individual aspects (subject, object, tools, etc.) are interdependent and therefore mutually constitutive. If a person moves from one activity system to another, the nature of the subject changes, is redefined in terms of the new activity system, including the identity, emotive characteristics, motive and motivation, responsibilities and obligation. More so, if *thinking* is thought as dialectical correlative to material praxis, then other than the material body and some habits move. This allows me to understand why the same scientist *thinks* so differently and with such different levels of success in the expert/expert think-aloud sessions compared to his or her own laboratory.

Steve: Let me return to moments where transfer *was* observed. Usually this happens beyond the boundaries of a particular study. Fortunately, I was able to gather such evidence with a group of fourth-grade children who had been writing an eco-mystery in class, writing about and with ecological concepts and discourse within mystery-narrative storylines. While their understanding of the science was evident in their situated writing as a classroom activity, it was spectacular when these same children engaged in scientific discourse spontaneously during an unrelated visit to the beach (Ritchie, Rigano, Duane, 2006). I note that SungWon and Michael acknowledge that “we do require an expanded time frame to understand how resistance mediates long-term changes in actions.” Nevertheless, I was wondering if they have similar evidence of “transfer” or even whether they think such evidence would enhance their theoretical position?

SungWon: Concerning the issue of “variant” and “invariant,” we need to think about how people interact and develop their collective object in an unfamiliar environment. Being unfamiliar implies not-being-grounded; cultural resources that may look

apparently available to another do not emerge as such to them. Michael and I have conducted an ethnographic study of an Asian student schooling at a North American University. In this study, we find emotionality constitutes important aspects of being aware of and enacting cultural possibilities (e.g., Hwang & Roth, 2005)—for example, solidarity is linked with and in part mediated by emotions. That is, what people know and how they learn are inseparable from what they feel in the new place. In some cases, it looks like that deep grounding in one context brings about the facilitation of becoming familiar with another.

Sasha: But I think you still have not addressed the issue of whether students could identify and interact with the underlying concepts if they were situated in relevant contexts. Providing a more rigorous description of when cross-contextual conceptual learning can emerge from embedded participation was quite interesting. However, I found myself wondering what it takes for students to learn non-material concepts and theories that would again be enlisted in other situations. In episode 5, for example, I thought the authors did a good beginning on this question, suggesting that “a culturally advanced person can lead other persons to go beyond their immediate understanding of the situation.” As a designer, I was left wanting more. What types of interactions, under what conditions, can a designer engage to aid learners in appreciating that the underlying conceptual tools have cross-context relevance?

Michael: There is also a difficulty in determining actions through designing, because there is an unavoidable (ontological) gap between plans and situated actions (Suchman, 1987). That is, even an acting person cannot know whether he or she acted according to a plan until after they have produced some outcome, which can then be evaluated after the fact against the goal. Rather than attempting to determine what happens in classrooms, I think it would be better to take the approach others have taken in designing not for specific outcomes to be produced within a system but for the various kinds of breakdowns that may occur (e.g., Winograd & Flores, 1987). This would take us quite a way toward fostering classroom environments that support the learning of classical concepts.

The other part of the question pertains to the question of concepts and meanings that are said to underlie some contextual act. To me, and this requires another book-length tour of argument, the purpose of schooling cannot lie in instilling specific concepts and theories—even in the most limited domains there are too many to be learned in a lifetime—but in providing students with resources that allow them to participate in diverse and multi-voiced conversations and to expand their action possibilities in whatever setting they might find themselves. Above all, I believe that students and adults need to have a sense of control over the object that defines their activity, the means they want to use, the kinds of division of labor they want to enact, and so on. How students can control and expand control over their life conditions needs to guide our educational theorizing.

Sasha: Reflecting back on the article, I am struck with the idea that design work might focus on establishing problems and providing tools and resources such that the learning/doing activity is likely to result in contradictions. Further, is the implication that these emergent contradictions are only meaningful, pedagogically, when they come about in such a manner that the learner experiences the resistance. It is at these points that she is likely to engage a sort of epistemic distance through which a critical

stance is adopted. This stance, while bound up in the local contextual particulars, often requires drawing on conceptual tools that are not bound solely to the local context; that is, in examining the disjoint, the learner may draw on the notion of, for example, triangulation to better understand why their design is not working correctly.

Steve: The explanation of the resistance|contradiction dialectic in relation to creating opportunities for learning has helped me make better links, or alternatively afforded me the opportunity to identify and then mediate between resistance and contradiction, with respect to children's design moves. Previously (Roth, Tobin, & Ritchie, 2001), I have (co-)written about the dialectical relationship between human and non-human actors in design activities where we argued that the evolving artifact "was talking back—figuratively telling them [i.e., the designers] the next step" (p. 145). "Talking back" was the best metaphor we could use to account for this mutually constitutive process. SungWon and Michael's description and illustration of the resistance|contradiction dialectic now provide the additional resources I needed to unpack what "talking back" means to me. I now think of "talking back" in terms of a learner who identifies resistance, stands back to objectify the contradiction, at which time there is a momentary opportunity for the learner to mediate the resistance, especially with additional human (e.g., teacher) or non-human (e.g., tool) resources. In this way, the learner moves back and forth (dialectically) between insider and outsider. Reflection on the situation also can produce the resources to help the learner modify his or her action possibilities.

Michael: The notion of *talking back* takes us quite a way to make the relation between the acting subject and its social and material worlds more symmetrical. At the same time, there is a fundamental asymmetry that we cannot overcome, because human beings are endowed with consciousness but pieces of wood, an artifact, or a tool are not subject to the same agency|patience dialectic that characterizes human beings.

Sasha: What I am wondering at this point is whether there is a non-material accounting or framework that we designers might leverage in our own work. In other words, much of the theorizing is in relation to a descriptive account, and I am wondering if the authors would feel comfortable in providing a prescriptive one for other designers. If they feel that this offering up a non-material framework that others might adopt was theoretically inconsistent with their convictions, then I would be curious why as well? Are prescriptive accounts ever appropriate? If so, what necessary conditions would the authors suggest that we attempt to design in to our curricula? What would their prescriptive framework look like?

SungWon: Yesterday in my class I introduced the design activity to University students who prepare to become physics teachers. I would prefer to talk about students' experiences after conducting a collective design activity, but I had to explain cases and what I learned from them. The issue in this kind of teaching is how we communicate with those who do not have concrete experience that our language refers to.

Michael: Sasha raises an important issue, though, concerning the extent to which learning can be planned. Klaus Holzkamp (1992), a critical psychologist who advanced and extended A. N. Leont'ev's work devoted an entire paper to articulate a

categorical answer to this question: the idea that learning processes in schools can be planned, managed, and determined is pure fiction. I suggest that we think of teaching as a process whereby teachers provide resources that allow students to expand their action possibilities, whatever they decide these may be, rather than seeking to determine *specific* learning outcomes.

Sasha: As a Montessori child, I tend to agree with your sentiment in terms of what constitutes a meaningful education. As a situativity theorist who believes that meaning and knowing exist in the dynamic flow, I also agree with you theoretically. However, as a learning scientist who develops curriculum for large numbers of teachers both in the United States and abroad, I find myself struggling with the tension of supporting pre-determined versus emergent goals. In my work, I have suggested that a useful pedagogical move is to develop curricular materials to support the emergence of particular goals that, if adopted, are likely to result in the production of specific resistances, which, to resolve, will require the enlistment of key concepts (Barab, Cherkes-Julkowski, Swenson, Garret, Shaw, & Young, 1999). The teacher's role is to support learners in noticing contradictions such that they become learner-owned resistances. At these points, a type of epistemic distance from, but always in relation to, the local context is likely to emerge. Core domain facts, concepts, principles, etc. can then be brought into the system, but as useful tools for resolving resistances—not as things to be memorized.

From this perspective, the focus of this design is on supporting the enlistment of particular intentions and resultant learning trajectories, not on the acquisition of particular knowledge. I might simply be trying to have my cake and eat it too :-). As I read Michael's comments, I am struck by the feeling that while practically desirable, this might be theoretically inconsistent and, even worse, result in simply propagating the very practices I hope to reduce.

3. Clarifying Meanings

Steve: Before I can appraise fully the empirical claims made in this article I need to seek clarification of some key terms used in the dialectics worked through the data. In admitting my intellectual struggle with the text, I take some comfort in Raapana and Friedrich's (2006) answer to the question: "Why is it almost impossible for a layman to understand the Hegelian dialectic?" Simply put, they assert: "That's because it was never written to be understood" (p. 7).

Michael: It is true, reading Hegel cold, without any preparation, is not easy. But reading Hegel in the context of reading other texts using dialectics from antiquity (e.g., Heraclites, Plato) to the present day (Derrida, Levinas, Nancy, Ricœur) via Spinoza, Marx, and Il'enkov allows us to appreciate the contribution this eminent thinker has contributed to philosophy. That not every layperson understands does not surprise me, because every discipline has its own genres and topics. Thus, talking to a car mechanic or a lawyer, most people do not understand and denote what they hear by *gibberish* or *jargon*. Why should everybody understand Hegel when few understand their lawyer, accountant, or car mechanic talk about salient issues in their fields?

Steve: I agree, it is unfair to apply the comment to dialectical approaches in research generally and this article in particular. However, it does flag the potential difficulty for a reader to navigate text built up around dialectical logic. This becomes even more problematic, for me, at least, when key terms that feature in the dialectics are “defined” or described in terms of the other component of the dialectic. Let’s take, for example, the contradiction|resistance dialectic. The authors’ attempt to distinguish between resistance and contradiction by writing: “Resistance denotes a response of the objective material world to the designers’ action by realizing their subjective intention” and “resistance is a subject-centered perspective, which we distinguish from contradiction, an idealized god’s eye perspective.” So what was “resistance” again? Is it opposition, either overt or passive? I do recall reading about resistance theory to explain underachievement of indigenous children, for example, in Westernized schools. Later, I read “expressions of an inner contradiction are denoted as resistance. A *contradiction*, on the other hand, requires the subject to step back from the immediate situation to be able to look at the experience from a distance to understand how inner *contradictions* in the system as a whole come to express themselves in its particular lifeworld” (emphasis added). What I find difficult in the last sentence is that *contradiction* is used as a reference to explain *contradiction*. How can dialectical texts be made easier to penetrate?

Sasha: I also had some difficulty resolving some of these. When I first sat down to read this it was with my two boys running around me in circles. Fifteen minutes later I realized I had no idea what I just read. So, I retreated to a more formal setting where I could interrogate the text in a more focused manner. In the paper, Hwang and Roth introduce this distinction between first and third person perspective, suggesting that some level of “distance” was necessary for learners to resolve identified contradictions and emergent resistances. I found myself having to engage in the same process. I first read the text as a participant on a journey, with a destination somewhat specified by the authors. However, I am sure that the particular journey that I undertook with the text and the one they intended differed but hopefully not so much that I couldn’t appreciate their argument. For me, once I had engaged the journey I then had to step back and work through my own resistances—one of these, ironically, being around the description of resistance.

Michael: I jump in here if I may to clarify. The problems of understanding lie in part in our difficulty at the time of writing to get out of the contradictory use of the concept of *contradiction*, which is, in dialectical thinking, the source of development and evolution (Il’enkov, 1977). There are two problems that have arisen in cultural-historical activity theory because of inaccuracies and fuzziness concerning the concept. First, in dialectical logic—including its embodiment in recent philosophical work concerning ontology and difference—an inner contradiction denotes the difference between a thing and itself. A prominent example of such a thing that is different from itself exists in the definition of the object/motive of activity, which simultaneously exists at a material and an ideal plane (A. N. Leont’ev, 1978). For Marx, this inner contradiction of commodity, which is expressed in its simultaneous occurrence as use-value (material) and exchange-value (ideal). Use-value and exchange-value are different, contradictory but one-sided conceptualizations of commodity. This contradiction is external to the thing, which is commodity only in the concrete setting of actual commodity exchange praxis.

The second weakness of the usage of the term by activity theorists lies in the fact that contradiction (etym: Lat. *contra-* against, and *dicere*, speak) is itself only a one-sided, consciousness-centered aspect of praxis; its dialectical complement is resistance (Bloch, 1964). The German language, in which the concepts originate, has a better way of conceptualizing the dialectical situation in the pair of *Widerspruch* (literally “to say” “against”) and *Widerstand* (literally, “to stay” “against”) to denote contradiction and resistance, respectively. In this way, not only thinking but also things in themselves are dialectical. Philosophers failed to appreciate resistance because, “contradiction, from the significant moment when it was objectively discovered, covered up resistance—the one within itself” (p. 109). Engeström (e.g., 1987), in whose work contradictions feature centrally as drivers of expansive learning, neither cleanly articulates the ideal|material dialectic of praxis nor the corresponding contradiction|resistance dialectic, by calling everything contradiction, including the breakdowns, resistances, obstacles, differences in opinion, mismatch of theoretical terms and practice, and so on.

Sasha: In my understanding, the design trajectory was filled with contradictions although only a handful may have entered the life-worlds of the participants such that a resistance emerged. To be clear, when there was a disjoint between the individual’s goal and the material happenings (the outcomes of action) a resistance was born. The focus of the article was in articulating the importance of epistemic distance, and the value of these resolutions for supporting non-material concepts and theories.

Michael: When you think dialectically, then you need to think in terms of contradiction|resistance. Now it may occur that resistance is experienced but in the lifeworld of the subject, contradiction does not yet exist—but this way of framing constitutes only the one-sided form. Praxis unfolds, and resistances and contradictions make themselves known at various moments, sometimes not even making it into the consciousness—a typical example are the “workarounds,” where people sidestep trouble, often unknowingly, by doing relevant things differently than designed.

Steve: I think my initial difficulty was reading the paper atomistically. Once I stepped back and re-read the paper in terms of the different perspectives; namely, outsider (i.e., third person or observer) and insider (i.e., first person or subject/learner), it fell into place. An outsider (third person) might observe a contradiction whereas a learner’s experience of resistance (first person) becomes an opportunity for learning. Furthermore, once a learner recognizes resistance the learner can step back in a pseudo-third person position to objectify the contradiction in its particular lifeworld. In what ways then would resistance and perturbation be similar and different? Is a perturbation limited to cognitive contradiction whereas resistance is experienced at the mind-body interface?

SungWon: The term “perturbation” reminds me of various strategies for “conceptual change” that science teachers often bring to their students. In many cases, students are confronted with a phenomenon independent of their intentions and without a history of interactions with the materials. The context and historical dynamics are removed from the conceptual structure and material world.

Sasha: This is a good start for addressing the problems I was trying to articulate. So what are the implications?

Michael: Again, my sense is that the conversation begins with the different aspects under which the whole activity unit expresses itself. We need to begin theorizing from practical activity, concrete human praxis, and then pose questions about perturbation. We have to do this because, as I showed in various places, what teachers think is a perturbation or cognitive conflict actually is not experienced as such on the part of the learner. Thus, students will not experience a conflict if their implicit theory allows them to perceive and describe events in ways that may be incompatible with the scientific conceptualization and perception; showing students more of these events neither leads to conflict—students still see them their ways—nor leads to change (Roth, 2006). The issue appears to me how we get out of this double bind, whereby students perceive events in non-scientific ways whereas perceiving and theorizing these events mutually constitute each other. What kind of resources support the simultaneous emergence of theory/concepts and perception?

Steve: I don't have a quick answer to this perplexing question, Michael. It seems to me that much of the research on conceptual change has also been unsuccessful in suggesting what sorts of resources are needed for students' conceptual learning. What is starting to concern me now is that researchers within the same field of science education may no longer be able to communicate with each other because they don't accept or want to understand the different perspectives brought to bear in considering the question. For example, a reviewer of a recent paper of mine that featured dialectic discussion, requested that I translate the discussion in plain language and simply develop a case to support each assertion. It is a challenge to clarify meanings of particular "in-house" constructs for those who choose to reside elsewhere.

4. Material vs. Non-Material and other Dualisms

Sasha: Let me clarify what I am meaning here. Much of the "grounding" work in these examples comes from working with perceptually tangible materials and situations. The move is in understanding under what conditions non-material concepts are enlisted such that they become tools for making sense of the local. In my work, I am frequently working with underlying concepts that are not perceptually tangible given the problems I present. For example, investigating a water quality problem in a simulation context through which students have to make sense of numeric values (Barab, Hickey, Sadler, Heisl, & Zucker, 2006). Rather than directly seeing the problem, student's interactions with the water are mediated by data about water quality indicators such as dissolved oxygen, phosphates, or nitrate levels. In one simulation, students initially develop a hypothesis based on discussions with virtual characters that they meet through moving an avatar around a virtual world. The local narrative that they come to understand from talking with people is eventually contradicted by the scientific information they later virtually gather. For students with prior experience and understanding, they are able to read these contradictions directly in the data while for other students these contradictions do not cause resistances—they fail to enter their life-worlds. In other words, for some students there is this sort of *epistemic distancing*, as they evaluate the data in relation to their now-revealed incorrect hypothesis. I am wondering if the same principles that the authors are advancing with respect to their material design activities operate on these less physically embodied "hands-on" activities. Said another way, can narratively

embodied problems enlist similar processes to these physically embodied problems or does some different transactive process unfold?

Michael: To me, all of this is a case of familiarity with the different resources (affordances, constraints) that people find in concrete praxis. Thus, I already pointed to the studies where experienced scientists with PhD degrees failed on the simplest tasks from introductory courses in their own discipline. Interestingly, when the performances of non-university scientists were compared to those of university scientists, the latter by far outperformed the former—a piece of evidence that we interpreted to be in favor of the familiarity hypothesis (Roth & Bowen, 2003).

Steve: I also think we touched on this issue earlier. Participating in activities that afford opportunities for the mediation of resistance and contradiction is crucial to learning. But what sort of learning? Improved use of tools in designing, for example, would be an expected outcome from designing activities, as we saw in this study. Even though SungWon and Michael extrapolated their claims to learning science from laboratory activities, this evidence was not included here. It makes sense to me that the practices embedded within the curricular activities would constrain learning to that which presented as an opportunity for the mediation of resistance|contradiction. Perhaps designing activities are less likely to provide opportunities for students to produce science concepts than laboratory activities that are more closely aligned with particular science concepts.

Michael: Again, I am less concerned about whether students can learn specific concepts and more about whether they can frame and resolve problems, deal with uncertainty, evaluate their accomplishments, and so on. In the process they learned. Whereas we may have failed to articulate the concepts students learned in this unit, they are thoroughly described and mapped against learning processes (Roth et al., 1999).

Steve: This is a crucial admission, Michael. It was starting to appear that you considered the identification of specific concepts within a school science curriculum as unimportant. Teachers' life-worlds are replete with contradictions. For example, we know that formal statements of standards or learning outcomes structure science curricula and yet research evidence constantly draws attention to the failures of such curricula. This paper and our subsequent musings appear to have been urging teachers to focus on the practical thinking of their students through students' participation in design activities, possibly at the expense of learning specified concepts. We have a responsibility to work within the constraints of formal schooling systems to create opportunities for change. We can't do so by dismissing current practices and ignoring teachers' formal obligations. The dialectics introduced in the paper help us to see different possibilities for learning science.

SungWon: I think Sasha's example points out dialectics of praxis and praxeology, that is, the emerging development of embodied experience (praxis) and "talk about praxis" (praxeology) grounded on one another (Roth, Lawless, & Tobin, 2000). For the student, their experiences in the cyber space must have not provided resources that the data refers to. Or, their talk must have not had to refer to their experiences in the cyber space. Epistemic distancing presupposes engagement in the sociomaterial world and constitutes itself as a new configuration of praxis. The students participated in the

design activity had opportunities to talk about their machines whenever they finished tasks.

About the development of hermeneutic experience, I think our experience of writing is a good example. When I write narratives about my research experience, my narratives initially refers to a specific event. The embodied practice of typing and materially produced texts then often lead me to step back from what I wrote and it brought forth an opportunity to take another look at it. Stepping back is quite physical given that I oftentimes find myself figuring out a long-standing problem when I have just turned off the computer. Embodied movement involved in language is another important issue.

Sasha: My final thought is based on some of the language that was used in the manuscript, and specifically the discussion of inner and outer worlds. The authors were very clear in stating their goal is to provide a non-dualist view of knowing and learning. I found the article and its continual description of happenings in terms of the dialectic to be a useful accounting for advancing a non-dualistic view of knowing and learning.

Michael: This is exactly what we are striving towards—Vygotsky’s idea of *thinking* and Bakhtin’s concept of *participative thinking* both aim at overcoming the divide between material and ideal and, simultaneously, between inner and outer—see my example of the DNA discovery, which followed the playing about with cardboard cutouts.

Sasha: However, as an ecological theorist, I couldn’t help but view some of the language as offering up a separation of inner (within body) and outer (in the environment) worlds. Gibson (1986), in advancing his ecological theory, also relied on the use of the dialectic to characterize many phenomena (Barab, Cherkes-Julkowski, Swenson, Shaw, Young, & Garret, 1999). This is most evident in his notion of affordances and effectivities, the former being possibilities for action in the environment taken with respect to the individual while the latter refers to abilities of the person taken with respect to the individual. His intention was to provide an ecological language, an “ecologese;” this vocabulary doesn’t fall into the dualist traps inherent to what one might term “mentalese” or a “physicalese.” Whereas a mentalese would credit meaning to the mind and a physicalese would credit it to the world, an ecologese positions it in the interaction—that is, in the ecology, flow or transaction. However, in this manuscript the authors state things like “expression of an *inner* contradiction” (italics added). I am wondering what is the difference between inner and outer? Is it simply indicating that something is occupying the inner/outer life-world of the individual, or is it referring to some “inner” world of the individual that is separate from the environment?

SungWon: Contradiction is a key concept of cultural historical activity theory. We find two approaches to conceptualizing “contradiction” in the current CHAT literature (Roth, 2005). Different from the one articulated in this paper, problematic situations oftentimes described as differences, discrepancies, inconsistencies, or antimonies are conceptualized as contradiction. We understand they are external contradictions, which are expressions of deeper inner contradictions and provide opportunities to find them.

Sasha: This is an interesting idea, but I do not think that it gets at the issue I am trying to raise.

Michael: Let me try. I think that I resolved the issue with the *inner* contradiction, which is the difference of an entity with itself. It is not inside or outside the person. Something *appearing* inside or outside a person always is but a one-sided expression, which we always find when an irreducible unit, such as a concrete cultural-historical activity, is reduced to this or that aspect. This, therefore, is a consequence when, in opposition to Vygotsky's (1986) requirement that units cannot be reduced, researchers nevertheless identify elements and then attempt to theorize activity in terms of these elements—subject, concepts, tools, objects, etc. Our theoretical language, which focuses on *participative thinking*, is essentially dialectical and therefore non-dualistic. Whether an aspect of participative thinking, which itself is only an aspect of praxis, occurs within our outside the human body is irrelevant to understanding thinking as such.

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